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Effects of exercise upon the cardio-vascular and respiratory systems

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EFFECTS OF EXERCISE UPON THE CARDIO-VASCULAR
AND RESPIRATORY SYSTEMS

by

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INTRODUCTION

Historical Sketch

Since the time that man has inhabited the earth he has consciously or unconsciously given heed to his physical condition. Different cultures have desired physical fitness for different reasons.

In every age there have been nations striving for national physical fitness so that they might have a strong army. Among these cultures are ancient Mesopotamia, the ancient Chinese, the Homeric Greeks, the Spartans, and the Romans. To this list could be added the United States in the time of World Wars I and II and Russia and China today.

There have been cultures who desired a high degree of physical fitness of their citizens for they believed that the maximum efficiency of the mind could be achieved only when the body was physically fit. Included in this group are the Athenians, and the European Aristocracy during the Renaissance period.

A look at the results of the last few Olympic games very well expresses the attitude of the different nations towards physical fitness. In the sprints and other events which call for short explosive bursts of energy the United States is definitely superior. But Russia and Scandinavian countries are outstanding in those events which call for prolonged activity, i. e., in events which demand that the contestants be in superior physical condition. In these nations the government encourages its citizens to participate in some sports program. In addition to the physical and esthetic advantages to the participants, the state gains in both the heightened physical efficienty and morale of its workers.

The United States today has very nearly fallen into a state of apathy as far as the physical condition of the majority of the population is concerned. Just recently our leaders have realized that as a nation we are "out of shape."

The result of a recent study of minimum physical fitness (Kraus, et al, 1954) comparing children from Europe with children of the United States showed that less than 10% of the European children failed the test. Of our own children 65% to 70% failed the same tests!

President Eisenhower no doubt had the results of this study in mind when he recently proclaimed May 3, 1959 as the beginning of "National Youth Fitness Week." Previously in July, 1956 the President issued an order setting up the President's Council on Youth Fitness whose duty it was to initiate a program to improve the physical fitness of the youth of our nation. (University of Illinois Publication, 1957).

Purpose of the Study

In many studies of physical fitness there have been attempts to arrive at a quantitative measurement which would reflect the physical condition of an individual. Physical fitness is indicated by the ability of the body to adapt to exercise or work, as shown by the return of the body processes to normal after performing an exercise or doing work. The more fit an individual is, the more rapid is the return to normal. Darling, (1947) has the following to say about physical fitness.

> "Fitness consists in the ability of the organism to maintain the various internal equilibria as closely as possible to the resting state during strenuous exertion, and restore promptly after exercise any equilibria which may have been disturbed."

Obviously, physical fitness gives evidence of the individual's ability to return to a homeostatic state.

The reasons for making this study were:

1. To simultaneously test the several circulatory and respiratory adjustments of the body to exercise. This has rarely been done, as usually circulatory measurements are tested apart from respiratory measurements.

2. To evaluate the methods used in measuring physical fitness from the standpoint of the physiological mechanisms involved.

3. To determine whether or not a program consisting of short term daily exercises would be sufficient to improve

or maintain the physical fitness of individuals who do not have the time to devote to keeping themselves in top physical condition.

People living in this area should be aware of the importance of physical fitness. A glance at the vital statistics of the autumn newspapers makes one aware of the increased number of deaths during hunting season, due to heart failure brought about by over-exertion. Generally practiced regular exercise would probably reduce the number of candidates for the obituary column.

Methods and Interpretation of Physical Fitness Studies

Pulse Rate

Investigators of physical exercise agree that the pulse rate increases considerably during exercise. Often it will more than double its resting rate (Eibel, 1948), (Dill & Brouha, 1937). In exercise the pulse rate progressively increases with the exercise up to as much as 200 beats per minute. It is important to note that the lowest post-exercise heart rate is found in trained individuals (Christensen, 1931), (Pere, 1952), (Reindell, 1943), and (Thirner, 1949), (Anrep, Pascual, and Roessler, 1936), (Heymans, 1950), (Lewis, 1925). Gallagher and Brouha, (1943). Brouha, *et al.* (1944) of the Physical Education Department at Harvard demonstrated that the post-exercise pulse rate decreased during a training program.

Despite all that is known about the augmentation of the heart rate, there is not complete agreement as to the factor to which this increase is due.

There are two classes of mechanisms which have been described as accelerators of the heart during exercise. The first of these is dependent upon the physical and chemical changes in the blood, and the second is dependent upon reflex activity. Bowen, (1903) and Buchanan, (1910), in separate investigations found that exercise will effect the heart rate in one cardiac cycle or less. The first cycle following the clenching of the first was shortened by 9%, and the second by 25%. The 25% increase took only 1.09 seconds. This very short latent period of the acceleration of the heart rules out the possibility that it is due to chemical products of skeletal muscular metabolism or the heat produced by muscular contraction, as neither could reach the heart in that short a time.

The direct action of metabolites on the heart or cardiac centers is also eliminated, along with reflexes arising from stimulation of the heart by heat (Mansfield, 1910). The possibility that the increase could be due to the inhibition of the vagal center by afferent impulses arising from the lungs due to increased respiration was disputed by Hering, (1895).

The elimination of chemical factors as the cause of cardiac acceleration leads to the conclusion that the increase is entirely nervous in character (Gasser and Meek, 1914). Johannson, (1895) has done work which supports this conclusion. His theory is that impulses along motor paths affect the cardiac centers in the medulla.

Athânsiu and Carvalls, (1898), felt that reflex movements alone were capable of causing the increase of heart rate. They found that paraplegic individuals had no acceleration of the heart rate when they were ordered to make voluntary efforts to move their disabled limbs, but an animal, poisoned with chloralose, and mechanically excited, experienced an increase of the heart rate if there were movement of the muscles. Therefore, they concluded that the voluntary motor impulses alone were insufficient to cause the acceleration of the heart rate, and that reflex movements were capable of producing it. They further concluded that working muscles increased the number if impulses to the acceleratory center, and in their passage through the medulla depressed the cardio-inhibitory center.

Hering, (1895) believed that the acceleration was primarily dependent upon the integrity of the acceleratory nerves but MacWilliam, (1893) and Hunt, (1899) felt the acceleration was dependent on the depression of the vagal center.

More recently Gasser and Meek, (1914) showed that the acceleration was due mainly to a decrease in tone in the cardio-inhibitory center. Their evidence, which confirmed the work of Bowen, (1903) and Buchanan, (1910) was: 1) electrocardiographs proving that the acceleration takes place in no longer than one cardiac cycle, 2) the acceleration continues until after the stimulation has been removed, and 3) the acceleration is reduced after section of the vagi.

Recovery Index

Some investigators feel that the Recovery Index,

$$\frac{\text{Duration of exercise in seconds}}{2 \times \text{Sum Pulse counts in recovery}}$$

determined after a suitable exercise, such as the Harvard Step-test is reputed to give satisfactory indication of the physical efficiency of young men (Brouha, *et al.* 1944), (Brouha, 1943) and (Montoye, 1953). Under a program of regular training the score becomes higher, and when training is insufficient or lacking the score decreases. The better the physical condition of a person the higher is his score. Brouha, *et al.* (1944) found athletes in training to have the highest scores. He further demonstrated that by a rigorous training program each individual could obtain his maximum efficiency, but further training could not improve his individual maximum. Superior scores can be obtained only by men who have the potential physical efficiency.

The Recovery Index as measured by Brouha, requires an individual to do the Harvard step-test at a rate of 30 times per minute for five minutes. If the subject cannot perform the test for the full period, his Recovery Index is determined for the total time of exercise.

From the preceding discussion it is apparent that an individual who is "out of shape" will have a higher heart rate after exercise than one who is in good condition, (Heyman, 1950), (Anrep, 1936), (Lewis, 1925), and may not be able to perform the test for the prescribed length, thus his Recovery Index would be low. It has also been pointed out that each individual can obtain his maximum efficiency but that the "maximum efficiency" is not the same for everyone. Therefore, one determination of the Recovery Index on an individual does not necessarily tell one whether or not he is at his maximum efficiency. If everyone is to be compared to a well-trained athlete who may have the potential for superior physical efficiency, then a single test cannot be considered valid for non-athletes.

The energy required for performing the Harvard step-test is high. For some individuals, fatigue may occur in two minutes, for others the test could continue for 10 minutes or longer. The motivation to continue the test when the subject begins to think he is tired must be a factor in whether or not the individual completes the test and, therefore, in the computation of the Recovery Index.

These thoughts may have been in the mind of the investigators who ran the test for one minute rather than five (Elbel 1948), (Miller and Elbel, 1946), (Elbel and Green, 1946). Since the Recovery Index is a much used tool in measuring physical fitness, it is imperative that we know whether or not the one-minute test with the factors of fatigue and motivation eliminated is comparable to the five-minute test.

In this study the Recovery Index was determined after an exercise lasting for 1 minute, as opposed to Brouha's standard of five minutes. The latter method we feel, may be prejudiced in favor of an individual in good condition, as he can easily do the step-test for five minutes.

If the step-test is done for five minutes the "motivation factor" is involved. One type of individual will complete the test regardless of physical discomfort to himself, and another will give up at the slightest discomfort.

Pulse-ratio.

Many authorities feel the pulse-ratio test,

$$\frac{\text{total pulse for 2 minutes after exercise}}{\text{resting pulse fo 1 minute}}$$

, to be a reliable and simple method by which physical fitness may be determined. (Phillips, et al, 1943), (Henry and Kleeberger, 1938), (Tuttle and Dickinson, 1938), and (Tuttle, 1931). Although it can not be used to compare individual physical fitness as it has a reliability correlation of only 0.744 (Phillips, et al, 1943), it is sufficiently high for group comparisons.

There is evidence that the pulse-ratio points out differences in physical efficiency (Tuttle, 1931) and (Henry and Kleeberger, 1938). Phillips, et al, (1943) found a definite tendency for persons with low resting heart rates to have a high pulse-ratio, and those with high resting heart rates to have a low-pulse-ratio. The coefficients of correlation between post-exercise pulse rate and the Recovery Index obtained by Montoye (1953) were, -0.637 and -0.782. Elbel,

(1948) found that after a strenuous exercise there was a large negative coefficient of correlation (-0.614) between the resting pulse rate and the increase due to exercise. He felt that this was an indication that every person approaches his maximum pulse rate during exercise. Individuals with a low resting pulse rate have the greatest percent increase, and persons with the highest resting rate have the least percent increase of pulse rate due to exercise. (Montoye, 1953).

It is apparent that Recovery Index and pulse-ratio measure the ability of the heart to respond to stress by increasing its contraction rate. This probably involves the cardiac reflexes and, therefore, the tone of the autonomic nervous system.

Blood Pressure

Since the heart is a part of a closed system, it would be expected that anything which affected heart rate would be reflected throughout the rest of the system. That this is the case can be shown by a study of blood pressure changes. Further, differences in heart rate between trained and untrained individuals leads one to expect differences in blood pressure readings also. This is confirmed by Wyman (1913), Herxheimer (1924), Ewig (1925), and Ackermann (1927). They have shown that more work is needed to increase the blood pressure in trained than in untrained individuals.

Exercise causes more of a change in the systolic pressure than in the diastolic pressure, since exercise results in an increased stroke volume, which causes an increase in the systolic pressure, but does not affect the diastolic pressure enough to cause it to rise much above the normal (Warner, et al, 1953), (Opdyke, 1952), and (Mansey, 1949). During exercise more blood is forced into the arterial system. This is a direct result of the effect of muscular exercise on the venous return (Bainbridge, 1915).

The increased output is compensated for by the greatly decreased peripheral resistance of the vascular system. (Barcroft, 1954), (Burton, 1953), (Edholm, 1950), (Matthes, 1955), (Ogden and Hall, 1949), (Pappenheimer, 1952), and (Wakim, 1951).

During the exercise the cardiac output (stroke volume x heart rate for 1 minute) is greatly increased, (Beard and Wood, 1951), (Burch and Sodeman, 1939), (Cournand, et al, 1942), (Greisheimer, et al, 1953), (Guyton, 1954), (Hamilton, 1944), (Landis, et al, 1946), (McDaniel and Sharpey-Schafer, 1944), (Sleator, et al, 1951), (Stead, 1947), (Kjellberg, 1949), and Thorner, 1935. This increase of cardiac output is associated with a rather marked decrease of the resistance to blood flow to the muscles used during the exercise (Petoen, et al 1936.) The resistance may be 20 to 50 times less than that of the resting state. This phenomenon of the flow of more blood through the same closed system may be analysed by means of Poiseuille's law (Guyton, 1956). From this one finds that the blood flow is inversely proportioned to the viscosity of the blood and the length of the vessel and directly proportioned to the blood pressure and the diameter of the vessel to the fourth power:

$$B.F. = \frac{(B.P.)}{(V)}\frac{(D.)^4 C}{(L)}$$

Where C is a constant depending on the units used for other factors.

From this formula we can see that resistance could be expressed as: $R = \frac{VL}{D^4}$, and that an increased diameter would allow more blood to flow through the system. Thus, the increased cardiac output increases the systolic pressure during exercise, while the lessened peripheral resistance permits a decrease of the diastolic pressure.

Although Salit and Tuttle (1944) do not agree, Wyman (1913), Herxheimer (1924), Ewig (1925), and Ackerman (1927), have shown that the blood pressure of persons in better physical condition is lower than that of people who are "out of shape."

Metabolic Rate

During exercise the skeletal muscles not only need more blood but are better supplied with blood. In addition, the low oxygen tension of the cells, the increased carbon dioxide, and acid metabolite formation also bring about a higher uptake of oxygen from the blood, resulting in an increased metabolic rate (Eggleton, 1936), (Gemmill, 1942), (Morehouse and Miller, 1948), (Schneider and Karpovich, 1948). The severity of the exercise is indicated by the metabolic rate

(Brock, et al, 1928). The calories per hour may rise from 65 during sleep to as high as 1100 while walking up stairs (Rose, 1938). The metabolic rate during severe exercise may for a short time rise to 20 to 40 times that of the resting state (Chambers and Summerson, 1950), (DuBois, 1936 and 1954), (Kleiber, 1947), and (Miller, 1954).

Ford and Hellerstein, (1957) determined that the Master two-step test, which is similar to the Harvard step-test, requires an energy expenditure of 1.485 ± .244cc of oxygen per minutes of exercise. This is about 6.8 times as much as the resting rate, or approximately 8.5 calories per minute; the everyday activity of climbing stairs is approximately equal to this.

Respiratory Rate and Respiratory Depth

The carbon dioxide tension of the blood is the major factor controlling respiratory rate and depth (Gray, 1950). An increased amount of carbon dioxide in the blood brought about by muscular exercise causes increased respiratory rate and/or depth.

Pulmonary Ventilation

Pulmonary ventilation is the amount of air breathed in one minute (rate x depth).

As the respiratory system is one of the most important limiting factors in performing strenuous physical exercise it must be included in a study of physical fitness. (Abramson,

1925) and (Kalvenen Niemi, 1953).

During a strenuous exercise the pulmonary ventilation rises to a level as high as 120-150 liters per minute. This is almost twice as high as that which can be brought about by post-exercise amounts of carbon dioxide in the body tissues (Gray, 1950). Therefore, there must be other factors involved which bring about an increase of the pulmonary ventilation. Some of the other possible factors are: 1) increased ionic concentration of the body fluids brought about by carbon dioxide and acids released during the exercise, 2) the increased metabolic rate of the body during the exercise acting as a stimulant to the respiratory center, 3) nerve impulses which may pass directly from the motor cortex to the respiratory center, 4) autonomic centers which are stimulated by exercise may stimulate the respiratory center, and 5), the rate of oxygen utilization may in some unknown manner increase the pulmonary ventilation (Gray, 1950). Gray, (1946, 1950), Lythgoe and Pereria, (1925), and Barman, et al, (1942) found that pulmonary ventilation lagged behind oxygen consumption, cardiac output, and pulse rate in recovering from exercise. It was postulated that this was due to prolonged stimulation of ventilation by the blood lactate (Lythgoe and Pereria, 1925) would be involved in the repaying of the oxygen debt.

Hawk (1903) reported the increase of erythrocytes immediately following exercise to be inversely proportional to the length of the exercise, varying from a few seconds to one hour, within physiological limits. Schneider and Havens (1914) and Schneider and Crampton (1935) agree that the hemoglobin and erythrocytes increase with exercise, but disagree as to whether or not the increase was proportionate. All of these investigators felt that the increase of hemoglobin and erythrocytes came from pools of blood which were quiescent in normal activities.

Leukocyte and Differential Counts

Larrabee, (1901) was one of the first to report an increase of leukocytes (leukocytosis). He found that this condition existed in four contestants of the Boston Athletic Association's Marathon Race. Hawk, (1903) concluded leucocytosis following exercises was due to leukocytes being released into the circulating blood from pools which were quiescent in normal activities. Schneider and Havens, (1914) found an increase of between 13.8% and 130.2% in leukocytes soon after exercise. They also found the neutrophils to increase from 9% to 45% in the differential count, and the lymphocytes to decrease from 14% to 55%. Meyer and Pella, (1947) found an increase in lymphocytes and a decrease of neutrophils in post exercise measurements, which is in complete disagreement with the results obtained by Schneider and Havens.

It is apparent that disagreement exists in several areas; 1) whether the Recovery Index should be calculated after an exercise of 1 minute or 5 minutes, 2) the correlation of the Recovery Index with the post-exercise pulse rate, 3) whether or not the increase of erythrocytes and hemoglobin is proportionate, and 4) whether or not the lymphocytes and neutrophils increase or decrease in post-exercise measurements.

It is clear that studies of circulation, respiration, metabolism and blood have not been made simultaneously. However, it was attempted in this study to accomplish this purpose, and to determine the physiological relationship of them.

METHODS AND MATERIALS

Subjects

Eight males were used in this study. Five of them were Physical Education majors whose ages ranged from 19 to 25. The other three subjects were graduate students whose ages ranged from 23 to 25.

Each of these subjects had been examined at the University Health Center, previous to the testing period and all subjects were considered to be in good health.

The five subjects who were Physical Education majors were engaged in a class in which they were taught how to administer group calisthenics. This class met three days a week for one hour. Two days a week was spent in learning how to administer the calisthenics and about one-half hour was spent in doing the calisthenics. Therefore, this could not be considered a conditioning class. None of these five subjects were engaged in any varsity sports, although three of them were participating in intramural football, and one was also playing ice hockey twice a week. The other two subjects of this group were working part-time after school at jobs which called for considerable exercise. These five subjects then had more physical activity than does the average college student.

The other three subjects, who served as controls, did not participate in any organized athletics, nor employment involving physical stress.

<u>Experimental Procedure</u>

The testing was done in the training room of the Men's gymnasium, hereafter to be referred to as the testing room. The study began in the second week of October and continued through the second week in December.

A definite schedule was followed for each subject. Each subject would come to the testing room on the day and at the time which had been appointed for him, so that he was always tested on the same day of the week and at the same time of day. After coming to the testing room and preparing himself to do the step-test, the subject would rest on a training table in a reclining position for ten minutes. At the end of this resting period the pre-exercise measurements were made.

<u>Circulatory Measurements</u>

<u>Blood Pressure</u> was measured with a Sphygmomanometer. The pulse rate was taken for 15 seconds at the radial artery. This was then multiplied by four to give the rate for one minute.

<u>Pulse Pressure</u> was calculated by taking the difference between systolic and diastolic pressures.

Blood Measurements

All of the blood samples were obtained by a finger puncture, a method which has been found to be as efficient as a venipuncture so far as the changes due to physical exertion are concerned (Schneider and Crampton, 1935). Single samples were taken for the pre-exercise and post-exercise measurements. Blood was collected every second week.

<u>Leukocyte</u>

The <u>leukocyte count</u> was done by drawing the blood sample to the 0.5 mark in a white blood cell pipette and diluting it with 1% acetic acid. A Spencer Bright-Line counting chamber was used in the enumeration of the leukocytes.

<u>Differential Count</u>

Blood was smeared on a clean glass slide and air dried. This smear was then stained with Wright's stain and one hundred cells were differentiated under oil immersion.

<u>Hematocrit</u>

Heparinized glass capillary tubes were used to collect the blood samples. A large drop of blood was allowed to collect on the finger and the end of the capillary tube was immersed in it. Capillary action drew the blood into the tube to the desired height, customarily about three-quarters of the tube length. The end of the tube away from the blood was flame sealed to prevent the blood from escaping. The tubes were then centifuged with the sealed end towards the periphery of the centrifuge, for four minutes at a rate of approximately 10,000 r.p.m., which gave a centrifugal force of about 12,000 times gravity. The centrifuge was a Phillips-Drucker Combination Clinical and Micro Hematocrit Centrifuge, Model L-708. The Plasma-erythrocyte ratio, or the per cent of blood cell volume, was then determined.

<u>Hemoglobin Content</u>

The acid-hematin method was used for this determination. The samples for this measurement were collected in a 0.2 mm hemoglobin pipette and were immediately diluted with 5 cc of 1% hydrochloric acid in a test tube. This mixture was allowed to stand for one hour in order for the hemoglobin to be liberated from the red blood cells, and for the color to be developed. The sample was transferred to a special colorimeter test tube and the percent of transmission read at 505mu with a Bausch and Lomb colorimeter. (Cohen and Smith, 1919). The colorimeter was calibrated and a hemoglobin curve drawn by using the Van Slyke method of determining blood hemoglobin (Van Slyke and Peters, 1932).

<u>Metabolic Measurements</u>

The <u>metabolic rate</u> was measured by a Benedict-Roth Metabolism machine. After the subject had rested for 10 minutes, he was connected to the mouth-piece of the machine and allowed to breath room air for one minute before being switched to oxygen from the machine. The metabolic rate was measured for four minutes. Body temperature was taken at the beginning of the test. Bell temperature was measured during the test.

The Step-Test

The step-test (Brouha, 1943) was then performed by the subject. To start the test the subject stood 10 inches from and facing an 18 inch bench. For a duration of 1 minute the subject stepped on and off the bench at a cadence counted out loud by the investigator or an assistant. At the count of "1" the lead foot was placed on the bench; at "2" the subject stepped up with the other foot, so that he was standing on the bench; on the count of "3" the subject stepped backward and down to the floor with the lead foot; at "4" the other foot was brought down to the floor so that the subject was again in the starting position. The count was rapid enough so that step "1" was being done every two second, or at a rate of 30 steps per minute. While performing the exercise the subject was required to straighten both knees at the completion of step "2". The subject was not to change the lead foot more than 2 times while performing the test, and preferably not at all.

Post-Exercise Measurements

Immediately upon completion of the step-test the subject again assumed a reclining position on the training table and the post-exercise measurements were taken. The pulse rate and blood pressure were taken immediately after the exercise, and again at 1 and 2 minutes after the exercise. The other measurements were taken in the same manner as the pre-exercise measurements.

__Calculated Data__

__Respiratory rate,__ and __respiratory depth__ were taken as direct measurements from the record of the metabolic rate. Pulmonary ventilation was calculated from these values.

__Recovery Index__

The Recovery Index (Brouha, __et al__ 1944) was used as an indication of physical fitness. In this study, the duration of exercise was 30 seconds.

In addition to this the Recovery Index was calculated on 2 students after [illegible] minutes exercise, and 20 students after 1 minute exercise and later after 5 minutes of exercise. The resting pulse rate and the post-exercise pulse rate for 1½, 2½, 3½ and on until recovery were taken. The purpose of this was to determine if 1 minute and 5 minute step-tests could be correlated with each other, and if they correlated with the maximum pulse rate and pulse-ratio.

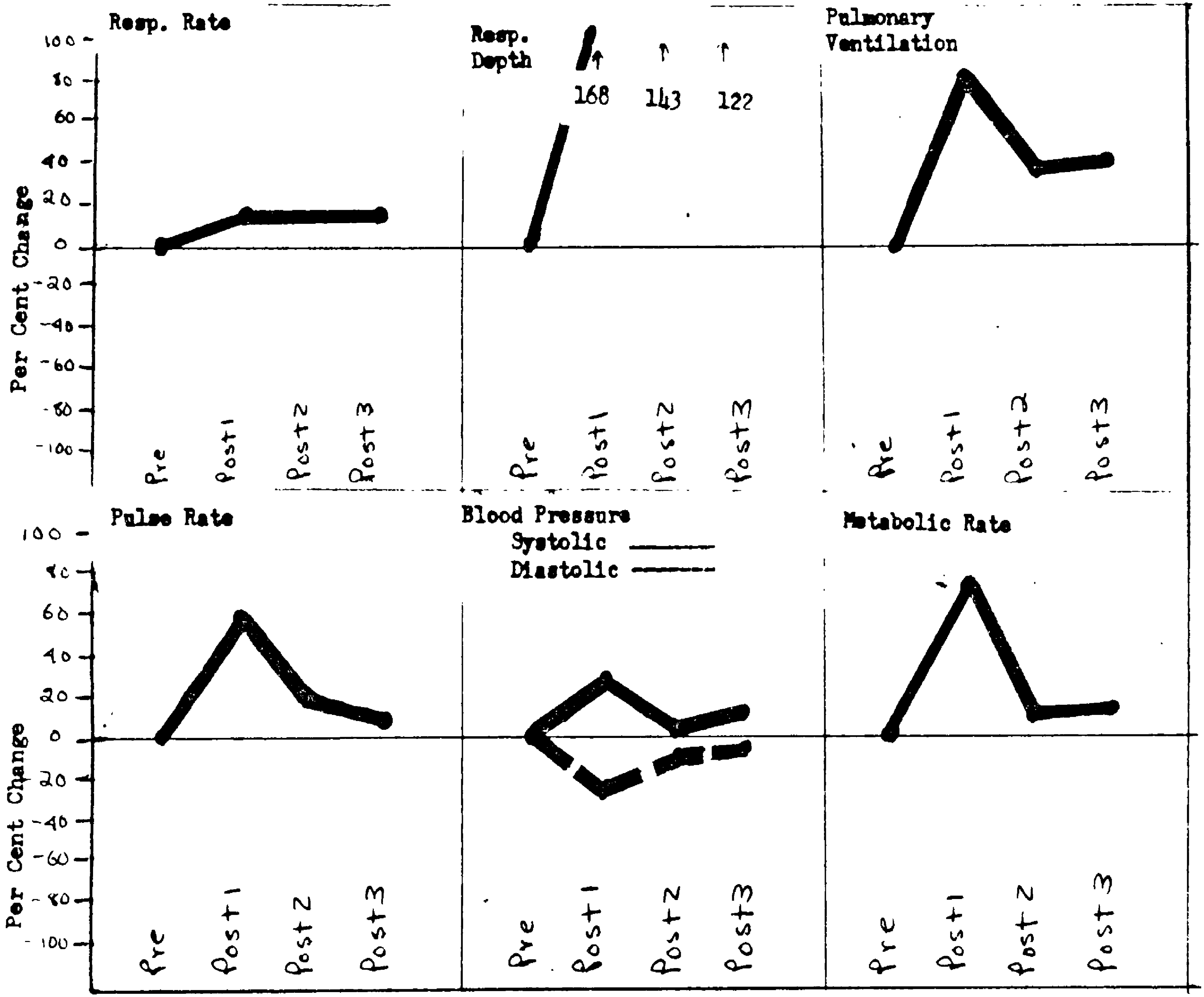
__Pulse-Ratio__

The pulse-ratio (Tuttle, 1931) was also used as an indication of the physical fitness of the group.

DATE AND RESULTS

__Effect of 1 minute exercise on cardio-vascular and respiratory systems.__

FIGURE I



Resp. Rate
Resp. Depth
168
143
122
Pulmonary Ventilation
Pulse Rate
Blood Pressure
Systolic
Diastolic
Metabolic Rate
Per Cent Change
Pre
Post 1
Post 2
Post 3

It is apparent from Figure 1 that the rate of return to normal of the various measurements is not the same after a 1 minute exercise. The blood pressure both systolic and diastolic returned to normal first, and at approximately the same rate, followed by the pulse rate and metabolic rate. These latter two returned at about the same rate. Next came the pulmonary ventilation, and then the respiratory depth which lagged far behind. The respiratory rate had not started to return to normal at the end of three minutes, but it had not increased significantly over the resting rate. Darman, _et al._ (1942) had previously found the same order of return to normal of these measurements.

<u>Pre- and post-exercise pulse rates:</u>

The coefficient of correlation between the pre-exercise pulse rate and the post-exercise rate, 0.7268, (Table XV, Appendix) is significant at the 5% level. While this is not a large enough value to be reliable for individual treatment, it is sufficiently large for group treatment. This agrees with Elbel (1948), who found that moderate exercise gives an insignificant coefficient of correlation between the pre-exercise and post-exercise pulse rate. Since the systolic pressure is correlated with the cardiac output, it has been analyzed from this that the increase of heart rate due to exercise is due mainly to decrease in tone of the cardio-inhibitory center (Gasser and Meek, 1914), (Bowen, 1903), and (Buchanan, 1910), and takes place in less than one cardiac cycle (Bowen, 1903) and (Buchanan, 1910).

It must then be concluded that the resting pulse rate of untrained persons is not correlated with the post-exercise pulse rate. This confirmed the conclusions of Gallagher and Brouha (1943), but contradicts Morehouse and Tuttle (1942) and Steinhaus (1923). It is possible that the discrepancy is due to the different durations and intensity of exercise.

TABLE I

Coefficients of Correlation

Factors Correlated	Value	Significance Level (Determined from T Test
Post-Pulse Rate and Systolic Pressure	0.7374	5%
Pre-Pulse Rate and Systolic Pressure	0.9136	Not significant
Pre-Pulse Pressure and Systolic Pressure	0.7919	5%
Post-Pulse Pressure and Systolic Pressure	0.9616	1%

In no instance did the pre-exercise blood pressure show any correlation with the post-exercise value, (Table XV, Appendix) in either the systolic or diastolic pressure.

Both the systolic blood pressure and diastolic blood pressure returned to normal more rapidly than did the other measurements, and their return was at approximately the same rate. This agrees with the results obtained by Bazman, et al.

(1942).

The coefficient of correlation between the pulse rate and the systolic blood pressure is significant at the 5% level, enough to indicate that t relationship probably exists between them. The increased heart rate resulted in an increased cardiac output (Beard and Wood, 1951), (Burch and Sodeman, 1939(, (Cournand, et al,1942), (Greisheimer, et al, 1952), (Guyton, 1953), (Hamilton, 1944), (Landis, et al, 1946), (McDaniel and Sharpey-Schaefer, 1944), (Sleator, et al,1951), and (Stead, 1957), which caused an increase in the systolic pressure, but does not effect the diastolic pressure significantly (Warner, et al, 1953), (Opdyke, 1952), and (Hansen, 1949). The decrease of the diastolic pressure is dependent on opening up of the peripheral capillaries, resulting in a decrease of the peripheral resistance (Guyton, 1956).

The significant coefficient of correlation between the post-exercise pulse pressure and systolic blood pressure was significant at the 1% level, (Table XV, Appendix) which showed the increase of the pulse pressure in exercise is due more to the increase of the systolic pressure than to the decrease of the diastolic pressure.

Respiration after exercise

As shown by Figure 1 a slight increase of respiratory rate was accompanied by a greatly increased respiratory depth. The hyperpnea was not due to the carbon dioxide increase alone (Bannister, et al, 1954). There is also a decrease of the threshold of the respiratory center to carbon dioxide, and perhaps to lowered pH. The lowered threshold continues for some time after the exercise and the hyperpnea have terminated (Bannister, et al. 1954) Also involved is the lowered oxygen tension of the blood which lowers the threshold of the respiratory center to carbon dioxide (Bannister and Cunningham, 1954). There is also an increased venous return brought about by the respiratory movements augmenting flow of the blood from the abdomen into the thorax (Hill, 1908) and (Bowen, 1904).

The coefficient of correlation between the respiratory depth and the pulmonary ventilation is significant enough to show that the increased pulmonary ventilation during exercise is mainly a result of the increased respiratory depth and not to the respiratory rate.

Looking at the picture as a whole it may be seen that the cardio-vascular system returns to normal more rapidly than does the respiratory system. The delayed homeostasis of the respiration is probably due to the lowered sensitivity of the respiratory center to carbon dioxide, the excess of which must be "blown off" before respiration can return to normal. Lythgoe and Pereria (1925) and Barman, et al. (1942) found that pulmonary ventilation lagged behind oxygen consumption and pulse rate in recovering from exercise. This lag was contributed to the blood lactate causing the prolonged ventilation. Gray (1950) also felt that the carbon dioxide tension of the blood played a major role in bringing about the hyperpnea following exercise.

Metabolic Rate and Exercise

In moderate exercise Bannister, _et al._ (1954) found a linear relationship between oxygen consumption (metabolic rate) and the volume of air breathed. From Figure I it may be seen that these two measurements closely parallel one another up to the second minute after exercise. There it can be seen that oxygen consumption returns to normal more rapidly than does the amount of air breathed. There is then no linear correlation between the two. This is probably due to the fact that while the oxygen debt has been repaid, the excess carbon dioxide has not yet been blown off.

Erythrocytes

As changes in the hematocrit and the hemoglobin content were not significant (0-0624 Table XV, Appendix) it was assumed that the exercise used in this study was not strenuous enough to effect them, and that blood from storage depots was not called into use. In more strenuous exercises Hawk (1903), Schneider and Havens (1914), and Schneider and Crampton (1935) found increases of both of these factors. The drop in the diastolic blood pressure following exercise indicates that there was no change in blood viscosity, if Poiseulle's Law is considered applicable.

Leukocytes

The total leukocyte count showed a significant increase after exercise, but there was not a significant change of the differential count. Both of these points confirm the results obtained by Schneider and Havens, (1914). The differential count showed an insignificant decrease of neutrophils and an insignificant increase of lymphocytes. This hints of the neutropenia and lymphocytosis found after exercise by Meyer and Fella (1947). This is also the condition found in cases of stress (Schulz, 1929). It can be assumed then that the 1 minute exercise, although minor, served as a stress to the organism.

The source of the increased number of leukocytes was probably the release of leukocytes from pools which were quiescent in normal activities (Mauk, 1903).

Thus, it can be seen that there are two cycles involved in exercise. First, there is the increased physuological activity due to the exercise, and the second cycle is the return to normal of any body functions disrupted (Darling, 1947).

Evaluation of Methods

TABLE II

Coefficients of Correlation

Factors Correlated	Value	Significance Level
Recovery Index and Maximum Pulse Rate	-0.9619	1%
Recovery Index and Systolic Pressure	-0.7702	5%

Pulse Rate and Recovery Index.

Between the Recovery Index and the resting pulse rate there was an insignificant coefficient of correlation, (Table XV, Appendix). Assuming that the Recovery Index is valid this indicates that the resting pulse rate is of no use in evaluating physical fitness. This was stated by Elbel and Holmer (1944).

The coefficient of correlation between the Recovery Index and the maximum pulse rate is significant at the 1% level. Montoye (1953) also obtained a large negative coefficient of correlation between the Recovery Index and the maximum pulse rate. That is, we would find that persons with higher Recovery Indices tend to have the lower maximum pulse rates. However, the Recovery Index is inherently higher for persons who have lower maximum pulse rates, thus making it doubtful that the Recovery Index is a valid indication of physical fitness.

Recovery Index and Blood Pressure

The coefficient of correlation between the Recovery Index and the diastolic blood pressure is insignificant, (Table XV, Appendix). Then assuming the Recovery Index to be valid it would seem that the diastolic blood pressure is useless as an indication of physical fitness. This is not what would be expected, for it is known that trained persons have a better blood supply to the muscles via more capillaries, and are thus able to reduce the peripheral resistance more than untrained persons.

The coefficient of correlation between the Recovery Index and the systolic blood pressure was found to be significant at the 5% level, (Table XV, Appendix). From this it would appear that the systolic pressure could be used as an indication of physical fitness, of a group but not of individuals. Between the two groups used in this study the difference was not significant. Also the coefficient of correlation is negative, which would lead one to expect a lower systolic blood pressure after exercise. The difference of the systolic pressure of the groups, of which the P. E. majors did have a slightly lower value was much too small to be sifnigicant, and could be included in the error of reading the gauge. That the systolic blood pressure is not a valid evaluation of physical fitness is supported by Salit and Tuttle (1944).

Recovery Index and Respiratory Measurements

The coefficients of correlation between the Recovery Index and all of the respiratory measurements were insignificant, (Table XV, Appendix). Also the respiratory measurements had insignificant coefficients of correlation with the other measurements of physical fitness. Assuming that the Recovery Index is a good quantitative evaluation of physical fitness, the respiratory measurements can definitely be regarded as being useless as an indication of physical fitness.

Recovery Index and Blood Measurements

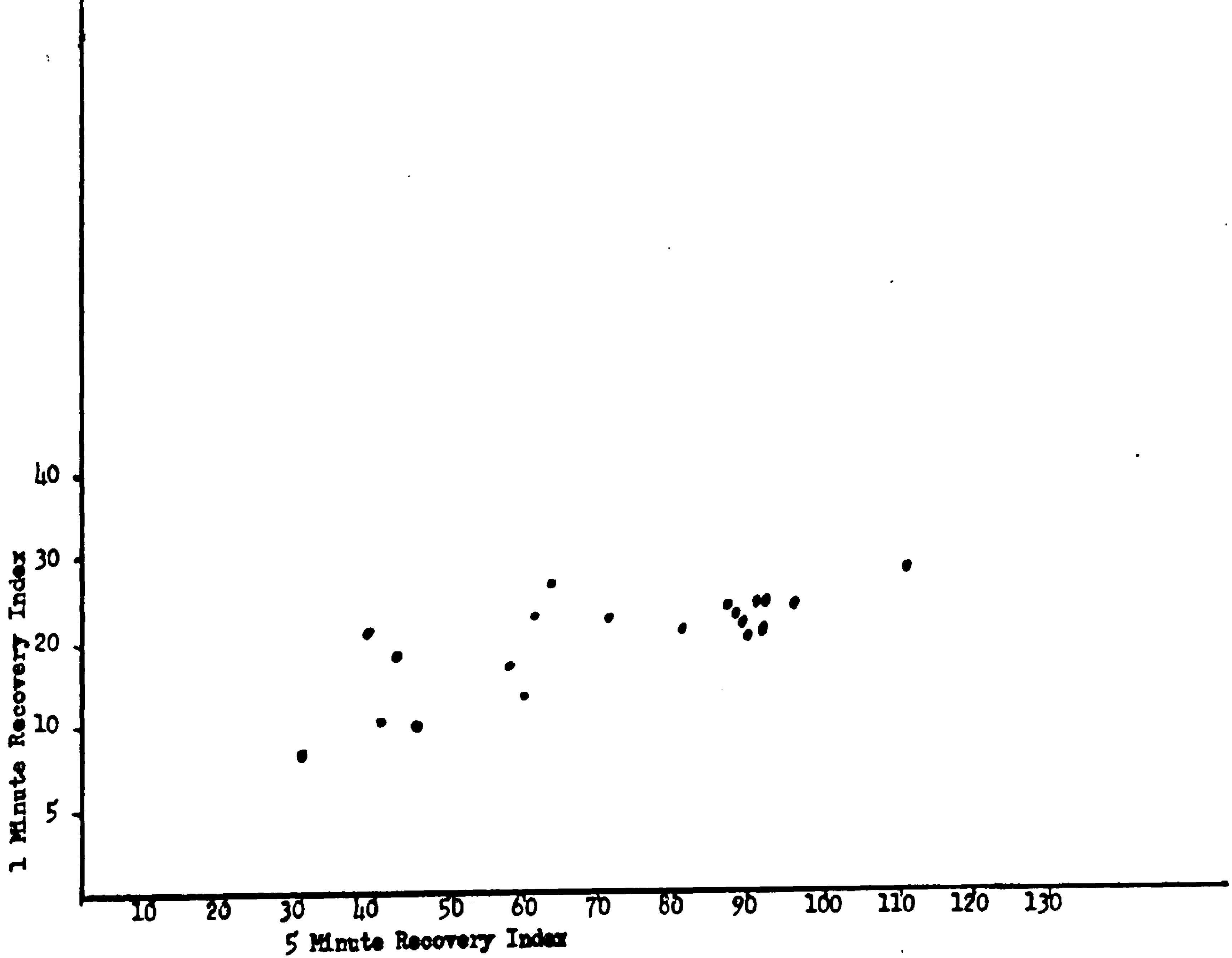
Blood Measurements could be regarded as useless as indicators of physical fitness for they proved to have insignificant coefficients of correlation with the Recovery Index, or the other measurements, (Table XV, Appendix), but again it must be assumed that the Recovery Index is valid if such an assumption is to be made.

Comparison of Recovery Index after a 1 minute exercise with that after a 5 minute exercise:

The Recovery Indices for 25 students from a physiology class were determined after a 1 minute exercise and after a 5 minute exercise. The coefficient of correlation between these two ways of determining the Recovery Index was insignificant, showing that a 1 minute exercise is not valid for calculating the Recovery Index, if we assume that the 5 minute exercise is valid. Figure II shows that the relationship between the two definitely is not significantly linear or even that they were closely correlated. The Recovery Indices of these students were also found to have insignificant coefficients of correlation with the resting pulse rate and the maximum pulse rate.

The lack of correlation between the Recovery Indices of the P. E. majors, graduate students, and the physiology class with the resting pulse rate, blood pressure, and respiratory and metabolic measurements causes us to question the Recovery Index as a valid evaluation of physical fitness as defined earlier. In fact, one begins to question whether or not the Recovery Index is measuring physiological

FIGURE II



1 Minute Recovery Index
5
10
20
30
40
5 Minute Recovery Index
10
20
30
40
50
60
70
80
90
100
110
120
130

functions, in that it is not correlated with them. It begins to appear that the Recovery Index deals with factors such as motor skill and co-ordination rather than with physiological reactions.

A number of investigators have relied upon the Recovery Index as determined after a 1 minute exercise to evaluate physical efficienty (Elbel, 1948), (Tuttle and Dickinson, 1938), (Morehouse and Tuttle, 1942), (Miller and Elbel, 1946), and (Elbel and Green, 1946). The lack of correlation between the 5 minute Recovery Index and the 1 minute Recovery Index casts a shadow of doubt upon the validity of the results obtained in these studies.

TABLE III

Long-term Evaluation of the

Recovery Index and Pulse-Ratio

Factors	P. E. Majors	Grad. Students	Group
Recovery Index			
Beginning	24.1	21.5	23.1
End	23.1	17	20.8
Per Cent Change	-4.5%	-21%	-10%
Pulse-Ratio			
Beginnig	2.5	2.7	2.6
End	2.8	3.1	2.9
Per Cent Change	-12%	-51.5%	-10.4%

Both evaluations of physical fitness, the Recovery Index and the Pulse-ratio, as shown in Table III, show a decrease at the end of the study. In each case, however, the decrease is insignificant ($t = 0.5$ and 0.9). Contrary from what is shown by the values of the Recovery Index, the subjects felt that it was easier to perform the exercise at the end of the study than at the beginning. This could be due to increased skill at performing the test, however. At any rate it would seem that the Recovery Index and pulse-ratio indicate that the amount of exercise undergone by either group of students was not enough to even maintain the physical fitness of the subjects. However, in light of the fact that the validity of the Recovery Index has been shown to be of doubtful value the subjective evaluation of the P. E. majors may be an indication that the amount of short term exercise undergone by the P. E. majors is enough to have slightly increased their physical fitness during the duration of the study.

The resting pulse rate, the maximum pulse rate, the systolic and diastolic blood pressure, respiratory rate, respiratory depth, pulmonary ventilation, hemoglobin content, and the hematocrit did not show a significant change, (Table XIV, Appendix) at the end of the study from the values at the beginning of the study in either the P. E. majors or the graduate students. This is indicative of the fact that the short term exercises undergone by the P. E. majors was not rigorous enough to exert any effect upon the production of erythrocytes or hemoglobin, and probably was not enough to alter the physical condition of them to any great extent. The leukocytes, however, did show a significant increase during the study. This is probably due to seasonal variation as winter was rapidly approaching. Too, this indicates that under slightly stressful conditions, white blood cells are liberated into the blood more rapidly than are red blood cells. This is probably due in the main part to the body's integrated effort to resist stress or changes brought about by it.

From this study it may be seen that the body is so integrated that it returns quickly to normal any factors which may have been disrupted by exercise, and that the recovery is efficient and in as short a time as possible.

Summary and Conclusions:

Physiological Mechanisms:

During the 10 week period of this study the physiological functions which were measured weekly did not show significant changes at the end of the term.

Following exercise the diastolic and systolic blood pressure returned to normal first and at approximately the same rate. Then came the pulse rate, followed by the metabolic rate. The pulmonary ventilation lagged behind the metabolic rate due to the carbon dioxide content of the blood, and had not returned to normal by 3 minutes after the exercise. Respiratory depth underwent a very great increase due to the exercise, and lagged behind the cardio-vascular measurements as did the respiratory rate. The Recovery Index is a doubtful evaluation of physical fitness as it does not correlate with the other measurements of physical fitness.

Effect of Exercise:

The respiratory rate increases the least following exercise, and the respiratory depth increases the most bringing about the increase of pulmonary ventilation. The systolic blood pressure increases more than the diastolic pressure decreases.

Evaluation of Methods:

The validity of the Recovery Index has not before been determined in the light of: a) physiological changes and b) subjective evaluation of the subjects. By determining the Recovery Index and considering these two points, it was concluded that the Recovery Index may not be a valid evaluation of physical fitness.

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PULSE RATE

Subject		Pulse Rate by Weeks 1	2	3	4	5	6	Mean	% of Normal
* Shapiro	Pre	92	76	88	76			83	
	Post 1	100	120	128	144			123	148%
	Post 2	80	124	100	88			98	118%
	Post 3	88	108	92	84			93	112%
* Osborn	Pre	80	72	88	72			78	
	Post 1	96	128	140	135			128	164%
	Post 2	88	86	96	88			89.5	115%
	Post 3	88	92	94	88			90.5	116%
Buckingham	Pre	64	56	72	52	64	60		
	Post 1	66	80	80	128	120	80	92.3	154%
	Post 2	64	56	52	68	60	60	60	100%
	Post 3	---	56	56	72	64	60	61.6	103%

Formula for Determining the Coefficient of Correlation (r)

$$r = \frac{n\Sigma xy - \Sigma x \Sigma y}{\sqrt{n\Sigma x^2 - \Sigma(x)^2}\quad\sqrt{n\Sigma y^2 - \Sigma(y)^2}}$$

Formula for the <u>t</u> Test

$$t = \frac{\bar{X} - \bar{Y}}{\sqrt{\dfrac{\dfrac{\Sigma x + \Sigma y}{(n_x n_y)\ (n_x + n_y - 2)}}{n_x + n_y}}}$$

and when $n_x = n_y$

$$t = \frac{\bar{X} - \bar{Y}}{\sqrt{\dfrac{\Sigma x + \Sigma y}{n_x(n_x - 1)}}}$$

TABLE I
(Continued)

PULSE RATE

Subject		1	2	3	4	5	6	Mean	% of Normal
Rummel	Pre	68	68	68	56	68		65.6	
	Post 1	128	144	128	124	156		136	207%
	Post 2	80	104	80	96	92		90.4	138%
	Post 3	76	72	68	84	84		76.8	117%
Feklewsky	Pre	92	80	76	96	108	88	90	
	Post 1	156	128	124	120	160	156	140.7	156%
	Post 2	120	100	108	115	116	92	108.5	121%
	Post 3	96	96	84	86	116	88	93.3	104%
* Farmer	Pre	80	72	72	76	64		72.8	
	Post 1	116	96	96	137	132		115.4	159%
	Post 2	96	88	88	96	92		92	126%
	Post 3	86	80	84	78	88		83.2	114%

TABLE I
(Continued)

PULSE RATE

Subject		1	2	3	4	5	6	Mean	% of Normal
Buettner	Pre	60	72	56	60	60		61.6	
	Post 1	86	128	104	80	88		97.2	158%
	Post 2	72	88	56	56	64		67.2	109%
	Post 3	68	68	64	56	60		63.2	103%
Smith	Pre	68	64	68	72	64		67.2	
	Post 1	82	120	108	120	124		110.8	165%
	Post 2	70	64	72	72	80		71.6	107%
	Post 3	--	64	72	72	72		70	104%

Mean of	Pre	75.5	70	71	73.5	69.3
% Change of 1		137%	169%	160%	168%	180%
% Change of 2		111%	127%	115%	116%	121%
% Change of 3		111%	114%	108%	105%	117%

Normal = 100% * = Graduate Students

TABLE II

BLOOD PRESSURE

Subject		Blood Pressure by Weeks 1	2	3	4	5	6	% of Systolic of Normal	% of Diastolic of Normal
* Shep	Pre	132/62	142/80	120/84	108/82			100%	100%
	Post 1	172/48	180/64	178/82	158/0			137%	+ 62.9
	Post 2	140/52	180/66	140/82	138/60			110%	+ 84.4
	Post 3	132/66	168/68	132/80	118/78			109%	+ 94.8
*Osborn	Pre	114/76	122/78	118/70	132/95			100%	100%
	Post 1	156/46	180/64	174/62	139/80			134%	+ 74.6
	Post 2	126/66	150/60	154/70	128/80			115%	+ 86.5
	Post 3	116/70	134/60	134/68	118/70			103%	+ 83.6
Buck	Pre	118/64	118/78	104/66	110/60	112/64	106/78	100%	100%
	Post 1	138/62	168/60	128/52	145/56	144/60	134/50	127.9%	82.8%
	Post 2	116/62	122/78	110/66	132/60	140/64	112/68	109.3%	97.1%

TABLE II
(Continued)

BLOOD PRESSURE

Subject		Blood Pressure by Weeks 1	2	3	4	5	6	% of Systolic of Normal	% of Diastolic of Normal
	Post 3	---	110/70	106/66	126/56	120/62	108/68	102.1%	194.3%
Rummel	Pre	120/74	116/74	122/78	124/72	108/76		100%	100%
	Post 1	168/72	194/52	202/68	192/62	158/58		143%	+ 83.4%
	Post 2	132/74	132/56	138/72	152/68	118/52		114%	+ 86.1%
	Post 3	120/70	130/72	128/76	144/66	108/70		107%	+ 94.7
Pek	Pre	132/70	132/62	128/66	118/66	122/58	122/68	100%	100%
	Post 1	204/30	194/46	184/54	170/20	184/0	142/32	143%	+ 46.6%
	Post 2	158/62	160/50	168/54	144/64	150/54	148/50	123%	+ 85.7%
	Post 3	132/70	140/60	140/58	132/54	138/58	124/64	107%	+ 93.4%
*Farmer	Pre	134/70	134/68	124/58	134/60	132/78		100%	100%
	Post 1	174/60	184/20	168/20	174/34	178/38		133%	+ 51.5

TABLE II
(Continued)

BLOOD PRESSURE

Subject		Blood Pressure by Weeks 1	2	3	4	5	6	% of Systolic of Normal	% of Diastolic of Normal
	Post 2	152/62	150/58	158/60	162/60	178/42		122%	+ 86.8%
	Post 3	146/60	152/60	128/68	160/68	152/88		112%	102.9%
Buet	Pre	138/60	140/62	128/54	122/60	118/64		100%	100%
	Post 1	172/70	178/54	170/42	172/48	154/44		131%	+ 88.7%
	Post 2	152/60	172/70	140/42	152/56	132/64		116%	+ 97.3%
	Post 3	142/54	172/70	132/62	140/60	130/64		111%	103.3%
Smith	Pre	120/54	132/48	124/70	114/52	124/68		100%	100%
	Post 1	------	168/20	184/38	172/38	142/0		136%	+ 47.6
	Post 2	124/66	148/50	162/48	132/50	130/0		113%	+ 88.9
	Post 3	------	146/50	148/52	128/52	118/0		100%	+ 76.4

#--Graduate Students

TABLE II
(Continued)

BLOOD PRESSURE

Subject	Blood Pressure by Weeks					
	1	2	3	4	5	6
Systolic						
Mean Pre	126	129.5	121	120.3	119.3	
% of Normal of 1	137%	139%	138%	136%	134%	
% of Normal of 2	109%	117%	121%	118%	118%	
% of Normal of 3	104%	111%	108%	111%	107%	
Diastolic						
Mean Pre	66.3	68.8	68.3	68.4	68	
* % Normal of 1	+83.6%	+66.6%	+78%	+61.8%	+48.9%	
* % Normal of 2	+96.5%	+88.7%	+90.5%	+91.1%	+70.1%	
* % Normal of 3	+98.	+92.7%	+97.1%	+92.1%	+83.8%	

TABLE II
(Continued)

BLOOD PRESSURE

		Blood Pressure by Weeks					
		1	2	3	4	5	6
		* Normal = 100%					
Subject		Mean by Subjects Systolic and Diastolic					
Shapiro	Pre	125.5/77					
	Post 1	172.0/48.5					
	Post 2	149.5/65					
	Post 3	137.5/73					
Osborn	Pre	121.5/79.8					
	Post 1	164.3/59.5					
	Post 2	139.5/69					
	Post 3	125.5/67					

TABLE II
(Continued)

BLOOD PRESSURE

Subject		Mean by Subjects Systolic and Diastolic
Buck	Pre	111.3/58.3
	Post 1	142.8/56.7
	Post 2	122.0/66.3
	Post 3	114.0/64.4
Rummel	Pre	118.0/74.8
	Post 1	184.8/62.4
	Post 2	134.4/64.4
	Post 3	126.0/70.8

TABLE II
(Continued)

BLOOD PRESSURE

Mean by Subjects

Subject		Systolic and Diastolic
Peklesky	Pre	125.7/65
	Post 1	179.7/30.3
	Post 2	154.7/55.7
	Post 3	134.3/60.7
Farmer	Pre	131.6/66.8
	Post 1	175.6/34.4
	Post 2	160.0/58
	Post 3	147.6/68.8
Buettner	Pre	129.2/60
	Post 1	169.2/53.2
	Post 2	149.6/58.4
	Post 3	143.2/62

TABLE II
(Continued)

BLOOD PRESSURE

Subject		Mean by Subjects Systolic and Diastolic
Smith	Pre	122.8/50.4
	Post 1	166.5/24
	Post 2	139.2/44.8
	Post 3	135.0/38.5

TABLE II
(Continued)

BLOOD PRESSURE

Mean by Weeks

Systolic and Diastolic

	1	2	3	4	5
Pre	126.0/66.3	129.5/68.8	121.0/68.3	120.3/68.4	119.2/68
Post 1	172.0/55.4	180.8/45.8	167.3/53.3	164.0/42.3	160.0/33.3
Post 2	137.5/64	151.6/61	146.3/61.8	142.5/62.3	141.3/47.7
Post 3	131.3/65	144.0/63.8	131.0/66.3	133.3/63	127.7/57

TABLE 11-A

PULSE PRESSURE

Subject		Pulse Pressure by Weeks 1	2	3	4	5	6	% of Normal
* Shapiro	Pre	70	62	36	26	--	--	100%
	Post 1	124	116	96	158	--	--	254.5%
	Post 2	88	114	58	78	--	--	174.2%
	Post 3	66	100	52	40	--	--	132.9%
* Osborn	Pre	38	44	48	37	--	--	100%
	Post 1	110	116	112	59	--	--	237.6%
	Post 2	60	90	84	48	--	--	168.7%
	Post 3	46	64	66	48	--	--	133.9%
Buck	Pre	54	40	36	40	40	28	100%
	Post 1	76	108	76	89	84	84	208.7%
	Post 2	54	44	44	62	76	44	130.8%
	Post 3	--	40	40	70	58	40	120.1%

TABLE II-A
(Continued)

PULSE PRESSURE

Subject		Pulse Pressure by Weeks 1	2	3	4	5	6	% of Normal
Rummel	Pre	46	52	44	52	42	—	100%
	Post 1	116	142	134	130	100	—	263.5%
	Post 2	68	76	66	84	66	—	150.0%
	Post 3	50	58	52	78	38	—	116.9%
Peklewsky	Pre	62	70	62	52	64	54	100%
	Post 1	174	148	130	150	184	110	245.9%
	Post 2	96	110	114	80	96	98	163.1%
	Post 3	62	80	82	78	80	60	121.4%
* Farmer	Pre	64	66	66	74	64	—	100%
	Post 1	114	164	148	140	140	—	211.4%
	Post 2	90	92	98	102	136	—	155.1%
	Post 3	86	92	60	92	74	—	120.9%

TABLE II-A
(Continued)

PULSE PRESSURE

Subject		Pulse Pressure by Weeks 1	2	3	4	5	6	% of Normal
Buettner	Pre	78	78	74	62	54	--	100%
	Post 1	102	124	176	124	110	--	169.9%
	Post 2	92	102	98	96	68	--	131.8%
	Post 3	88	102	70	80	66	--	117.3%
Smith	Pre	66	84	54	62	56	--	100%
	Post 1	--	148	146	134	142	--	221.3%
	Post 2	58	98	114	82	130	--	149.7%
	Post 3	--	96	96	76	118	--	149.8%
Pre		100%	100%	100%	100%	100%	--	
% Change 1		195.6%	214.8%	231.9%	243.1%	131.6%	--	
% Change 2		127.8%	146.1%	161.6%	156.1%	174.2%	--	* Graduate Students
% Change 3		111.2%	127.4%	123.9%	138.9%	132.2%	--	

TABLE III

PULMONARY VENTILATION
(ml per minute)

Subject		Pulmonary Ventilation by Weeks							
		1	2	3	4	5	6	Mean	% of Normal
* Shapiro	Pre	---	16.52	---	12	---	---	14.26	-13.75%
	Post	---	17	---	7.6	---	---	12.3	
* Osborn	Pre	---	---	3.12	7.14	---	---	5.13	242%
	Post	---	---	8.46	16.38	---	---	12.42	
Buck	Pre	---	5.76	6.08	10.2	8.5	4.8	7.07	196%
	Post	---	7.82	6.08	24.4	16.8	14.4	13.9	
Rummel	Pre	---	---	9.36	7.02	---	---	8.19	244%
	Post	---	---	20.52	19.5	---	---	20.01	
Pek	Pre	---	---	10.8	6.48	---	---	8.64	190%
	Post	---	---	26.1	6.72	---	---	16.41	

TABLE III
(Continued)

PULMONARY VENTILATION
(ml per minute)

Subject		Pulmonary Ventilation by Weeks 1	2	3	4	5	6	Mean	% of Normal
* Farmer	Pre	---	---	5.28	5.28	---	---	5.28	908%
	Post	---	---	21.78	74.16	---	---	47.97	
Buettner	Pre	---	---	4.8	9.66	3.08	---	5.85	265%
	Post	---	---	---	24.5	6.6	---	15.55	
Smith	Pre	---	---	3.63	4.32	4.55	---	4.17	402%
	Post	---	---	11.22	12.18	26.84	---	16.75	
Mean	Pre	---	11.14	6.15	7.76	5.38	2.4		
"	Post	---	12.41	15.69	23.18	16.75	7.2		
%	Change	---	111%	255%	298%	311%	300%		

*-Graduate Students

TABLE IV

Recovery Index

Subject	1	2	3	4	5	6	Mean
* Shapiro	22.4	17	18.8	19	---	---	19.3
* Osborn	22.1	19.6	18.2	19.3	---	---	19.8
Buckingham	---	31.3	31.9	22.4	24.6	30	28
Rummel	21.1	18.8	21.7	19.7	18.1	---	19.9
Peklewsky	16.1	18.5	19	18.7	15.3	18	17.6
* Farmer	20.1	22.7	22.4	19.3	19.2	---	20.7
Buettner	26.5	21.1	26.8	31.3	28.3	---	26.8
Smith	---	24.2	23.8	22.7	21.7	---	23.1
Mean	21.4	21.6	22.8	21.6	21.2	24	

Graduate Students = 19.9

P. E. Majors = 23.1

Group = 21.9

* = Graduate Students

TABLE V

METABOLIC RATE
(Cal/hr/m^2)

Subject		Metabolic Rate by Weeks 1	2	3	4	5	6	Mean	% of Normal
* Shapiro	Pre	---	114.4	---	79.1	---	---	96.75	103%
	Post	---	134.2	---	65.5	---	---	99.85	
* Osborn	Pre	---	---	54.9	59.9	---	---	57.4	132%
	Post	---	---	69.8	81.5	---	---	75.65	
Buck	Pre	---	49.5	49.7	58.8	59.8	69.1	56.2	132%
	Post	---	54.0	61.1	93.7	81.1	80.9	74.2	
Rummel	Pre	---	---	76.6	63.4	---	---	70.0	139%
	Post	---	---	99.5	95.2	---	---	97.4	
Pek	Pre	---	---	61.0	74.4	---	---	67.7	221%
	Post	---	---	85.3	214.6	---	---	49.9	

TABLE V
(Continued)

Metabolic Rate
($Cal/hr/m^2$)

Subject		Metabolic Rate by Weeks 1	2	3	4	5	6	Mean	% of Normal
* Farmer	Pre	---	---	45.6	52.9	---	---	49.3	218%
	Post	---	---	92.0	123.2	---	---	107.6	
Buettner	Pre	---	---	57.2	46.3	56.9	---	51.5	158%
	Post	---	---	---	75.1	87.3	---	81.2	
Smith	Pre	---	---	66.8	55.3	69.5	---	63.9	181%
	Post	---	---	125.4	76.7	145.7	---	115.9	
Mean	Pre	---	81.9	57.9	55.01	62.1	---		
"	Post	---	94.1	88.9	103.2	104.7	---		
%	Change	---	115%	153%	187%	169%	---		

* - Graduate Students

TABLE VI

RESPIRATION RATE

Subject		Respiration Rate Per Minute for Weeks 1	2	3	4	5	6	Mean	% of Normal
* Shapiro	Pre	—	14	—	19	—	—	16.5	106%
	Post	—	16	—	19	—	—	17.5	
* Osbern	Pre	—	—	13	17	—	—	15	138%
	Post	—	—	18	21	—	—	19.5	
Buck	Pre	—	15	16	16	17	16	16	116%
	Post	—	16	19	20	20	18	18.6	
Rummel	Pre	—	—	12	12	—	—	12	165%
	Post	—	—	19	15	—	—	17	
Pek	Pre	—	—	14	12	—	—	13	115%
	Post	—	—	15	15	—	—	15	

TABLE VI
(Continued)

RESPIRATION RATE

Subject		Respiration Rate Per minute for Weeks 1	2	3	4	5	6	Mean	% of Normal
* Farmer	Pre	---	---	12	14	---	---	13	123%
	Post	---	---	18	14	---	---	16	
Buettner	Pre	---	---	19	23	20	---	20.7	107%
	Post	---	---	19	24	23	---	22	
Smith	Pre	---	---	11	12	12	---	11.7	171%
	Post	---	---	21	20	19	---	20	

* - Graduate Students

TABLE VII

RESPIRATORY DEPTH

(ml)

Subject		Respiratory Depth Per minute By Weeks 1	2	3	4	5	6	Mean	% Change
* Shapiro	Pre	---	980	---	580	---	---	730	255%
	Post	---	2860	---	1120	---	---	1990	
* Osborn	Pre	---	---	800	550	---	---	630	212%
	Post	---	---	1360	1440	---	---	1440	
Buck	Pre	---	640	580	500	500	620	568	205%
	Post	---	1080	920	1420	1360	1040	1164	
Rummell	Pre	---	---	540	540	---	---	540	376%
	Post	---	---	1820	2240	---	---	2030	
Pek	Pre	---	---	960	760	---	---	860	278%
	Post	---	---	2740	2040	---	---	2390	

TABLE VII
(Continued)

RESPIRATORY DEPTH

(ml)

Subject		Respiratory Depth Per Minute by Weeks 1	2	3	4	5	6	Mean	% of Normal
# Farmer	Pre	---	---	640	660	---	---	650	419%
	Post	---	---	2440	3010	---	---	2725	
Buettner	Pre	---	---	600	620	520	---	580	224%
	Post	---	---	---	1560	1040	---	1300	
Smith	Pre	---	---	760	640	640	---	680	
	Post	---	---	1880	1580	1680	---	1713	
Mean	Pre	---	810	697	608	553	---		
"	Post	---	1970	1860	1801	1360	---		
%	Change	---	243%	267%	296%	246%	---		

- Graduate Students

TABLE VIII

DIFFERENTIAL COUNT

Subject	1	2	3	4	5	6	Mean	% of Normal
* Shapiro								
Neutrophils	---	---	---	---	---	---	---	---
Pre	---	---	---	---	---	---	---	---
Post	---	---	69.	---	---	---	---	---
Lymphocytes								
Pre	---	---	---	---	---	---	---	---
Post	---	---	20	---	---	---	---	---
Monocytes								
Pre	---	---	---	---	---	---	---	---
Post	---	---	---	---	---	---	---	---
Eosinophils								
Pre	---	---	---	---	---	---	---	---
Post	---	---	4	---	---	---	---	---

TABLE VIII
(Continued)

DIFFERENTIAL COUNT

Subject	1	2	3	4	5	6	Mean	% of Normal
Basiphils								
Pre	—	—	—	—	—	—	—	—
Post	—	—	1	—	—	—	—	
* Osborn								
Neutrophils								
Pre	—	—	37	52	—	—	44.5	111%
Post	—	—	40	59	—	—	49.5	
Lymphocytes								
Pre	—	—	59	41	—	—	50	93%
Post	—	—	58	35	—	—	46.5	
Monocytes								
Pre	—	—	4	4	—	—	4	75%
Post	—	—	2	6	—	—	3	

TABLE VIII
(Continued)

DIFFERENTIAL COUNT

Subject	1	2	3	4	5	6	Mean	% of Normal
Eosinophils								
Pre	--	--	0	3	--	--	1.5	--
Post	--	--	0	0	--	--	0	
Basiphils								
Pre	--	--	0	0	--	--	0	100%
Post	--	--	0	0	--	--	0	
Buckingham								
Neutrophils								
Pre	--	58	--	65	--	78	67	89%
Post	--	--	--	58	--	62	60	
Lymphocytes								
Pre	--	34	--	31	--	19	28	105%
Post	--	--	--	34	--	25	29.5	

TABLE VIII
(Continued)

DIFFERENTIAL COUNT

Subject	1	2	3	4	5	6	Mean	% of Normal
Monocytes								
Pre	--	9	--	4	--	5	6	167%
Post	--	--	--	8	--	12	10	
Eosinophils								
Pre	--	0	--	0	--	0	0	100%
Post	--	--	--	0	--	0	0	
Basiphils								
Pre	--	0	--	0	--	0	0	100%
Post	--	--	--	0	--	0	0	
Rummel								
Neutrophils								
Pre	--	--	64	--	--	65	64.5	82%
Post	--	--	58	--	--	48	53	

TABLE VIII
(Continued)

DIFFERENTIAL COUNT

Subject	1	2	3	4	5	6	Mean	% of Normal
Lymphocytes								
Pre	--	--	27	--	--	30	28.5	115%
Post	--	--	34	--	--	32	33	
Monocytes								
Pre	--	--	6	--	--	4	5	240%
Post	--	--	7	--	--	17	12	
Eosinophils								
Pre	--	--	1	--	--	0	1	100%
Post	--	--	1	--	--	1	1	
Basiphils								
Pre	--	--	1	--	--	2	1.5	67%
Post	--	--	0	--	--	2	1	

TABLE VIII
(Continued)

DIFFERENTIAL COUNT

Subject	1	2	3	4	5	6	Mean	% of Normal
Peklewsky								
Neutrophils								
Pre	--	--	71	--	64	--	67.5	
Post	--	--	58	--	66	--	62	
Lymphocytes								
Pre	--	--	27	--	30	--	28.5	87%
Post	--	--	25	--	25	--	25	
Monocytes								
Pre	--	--	2	--	5	--	3.5	300%
Post	--	--	12	--	9	--	10.5	
Eosinphils								
Pre	--	--	0	--	1	--	0.5	500%
Post	--	--	5	--	0	--	2.5	

TABLE VIII
(Continued)

DIFFERENTIAL COUNT

Subject	1	2	3	4	5	6	Mean	% of Normal
Basiphils								
Pre	--	--	0	--	0	--	0	100%
Post	--	--	0	--	0	--	0	
Buettner								
Neutmphils								
Pre	--	--	58	--	50	54	54	110%
Post	--	--	65	--	--	54	59.5	
Lymphocytes								
Pre	--	--	33	--	44	36	37.6	85.1%
Post	--	--	25	--	--	39	32	
Monocytes								
Pre	--	--	3	--	5	6	4.6	152%
Post	--	--	7	--	--	--	7	

TABLE VIII
(Continued)

DIFFERENTIAL COUNT

Subject	1	2	3	4	5	6	Mean	% of Normal
Eosinophils								
Pre	--	--	6	--	0	0	6	50%
Post	--	--	3	--	--	0	3	
Basiphils								
Pre	--	--	0	--	1	0	1	0%
Post	--	--	0	--	0	0	0	
*Farmer								
Neutrophils								
Pre	--	--	--	[illegible]	71	[illegible]	71	97%
Post	--	--		69	-69	--	69	
Lymphocytes								
Pre	--	--		--	25	--	25	112%
Post	--	--		--	28	--	28	

TABLE VIII
(Continued)

DIFFERENTIAL COUNT

Subject	1	2	3	4	5	6	Mean	% of Normal
Monocytes								
Pre	--	--		--	3	--	3	
Post	--	--		--	0	--	0	
Eosinophils								
Pre	--	--		--	1	--	1	300%
Post	--	--		--	3	--	3	
Basiphils								
Pre	--	--		--	0	--	0	100%
Post	--	--		--	0	--	-	
Smith								
Neutrophils								
Pre	--	--	59	71	52	52	58.5	94.8%
Post	--	--	62	69	38	53	55.5	

TABLE VIII
(Continued)

DIFFERENTIAL COUNT

Subject	1	2	3	4	5	6	Mean	% of Normal
Lymphocytes								
Pre	--	--	28	25	43	46	35.5	114%
Post	--	--	31	28	60	43	40.5	
Monocytes								
Pre	--	--	6	3	5	1	3.7	148%
Post	--	--	4	0	2	4	2.5	
Eosinophils								
Pre	--	--	1	1	1	1	1	150%
Post	--	--	3	3	0	0	1.5	
Basiphils								
Pre	--	--	3	0	0	0	0.75	112&
Post	--	--	0	0	0	0	0	

TABLE VIII
(Continued)

DIFFERENTIAL COUNT

	1	2	3	4	5	6	*
Neutrophils							
Pre			57.8	67.6			
Post			58.6	62			
Lymphocytes							
Pre			43.5	32.3			
Post			32.1	32.3			
Monocytes							
Pre			4.1	3.6			
Post			6.4	4.6			
Eosinophils							
Pre			1.6	1.3			
Post			2.4	0			
Basiphils							
Pre			1	0			
Post			0.1	0			

* = Graduate Students

TABLE IX

HEMOGLOBIN CONTENT

(gms./ 100 ml Blood)

Subject		1	2	3	4	5	6	Mean	% of Normal
*Shapiro	Pre	--	--	14.8	--	--	--	--	--
	Post	--	--	--	--	--	--	--	
* Osborn	Pre	--	--	12.5	--	--	--	12.5	97%
	Post	--	--	12.5	--	--	--	12.2	
Buckingham	Pre	--	13.0	--	12.5	--	13.3	12.93	99%
	Post	--	13.2	--	13.5	--	12.0	12.9	
Rummel	Pre	--	--	14.8	--	--	14.8	14.8	97%
	Post	--	--	--	--	--	14.5	14.5	
Peklewsky	Pre	--	--	13.5	--	14.5	12.5	13.5	95%
	Post	--	--	11.0	--	15.0	12.7	12.9	

TABLE IX
(Continued)

HEMOGLOBIN CONTENT
(gm.1 100 ml blood)

Subject		1	2	3	4	5	6	Mean	% of Normal
* Farmer	Pre	--	--	15.0	--	15.2	--	15.1	94%
	Post	--	--	13.2	--	15.5	--	14.3	
Buettner	Pre	--	--	15.5	--	13.5	14.5	14.5	[illegible]
	Post	--	--	15.5	--	11.6	14.0	13.7	
Smith	Pre	--	--	14.2	12.5	12.5	14.6	13.4	106%
	Post	--	--	14.0	15.0	15.2	13.0	14.3	
	Mean Pre	--	--	14.3	12.5	13.7	13.9	13.6	
	Mean Post	--	--	13.2	14.3	14.3	13.2	13.7	
	% of Normal	--	--	92%	114%	104%	97%	101%	

* - Graduate Students

TABLE X

HEMATOCRIT

Subject		1	2	3	4	5	6	Mean	% of Normal
* Shapiro	Pre	--	--	Broke	--	--	--	--	--
	Post	--	--	Broke	--	--	--	--	--
* Osborn	Pre	--	--	41	--	--	--	--	--
	Post	--	--	Broke	--	--	--	--	--
Buckingham	Pre	--	40	--	47	--	49	45.3	103%
	Post	--	45	--	45	--	50	46.7	
Reklewsky	Pre	--	--	48	--	48	45	47	102%
	Post	--	--	Broke	--	50	46	46	
* Farmer	Pre	--	--	Broke	--	52	--	52	94%
	Post	--	--	Broke	~~47~~	49	~~49~~	49	

* - Graduate Students

TABLE X
(Continued)

HEMATOCRIT

Subject		1	2	3	4	5	6	Mean	% of Normal
Buettner	Pre	--	--	Broke	--	44	48	46	103%
	Post	--	--	Broke	--	45	50	47.5	
Smith	Pre	--	--	Broke	48	48	42	--	
	Post	--	--	Broke	Broke	50	Broke	--	--
Rummel	Pre	--	--	46	--	--	48	47	98%
	Post	--	--	45.4	--	--	47	46.2	

Pre	47.4	101%
Post	47.8	

TABLE XI

WBC COUNT

Subject	1	2	3	4	5	6	Mean	% of Normal
* Shapire								
Pre	--	--	5200	--	--	--	5200	132%
Post	--	--	6900	--	--	--	6900	
* Osborn								
Pre	--	--	7450	--	--	--	7450	145%
Post	--	--	10850	--	--	--	10850	
Buckingham								
Pre	--	8000	--	3062	--	5000	5354	155%
Post	--	7850	--	8050	--	9400	8433	
Rummel								
Pre	--	--	10500	--	--	7100	8300	106%
Post	--	--	11050	--	--	5700	8375	

TABLE XII

MEAN VALUES

Factors	P. E. Majors	Graduate Students	Group
Maximum Pulse Rate	115.4	122.1	117.9
Pulmonary Ventilation			
Pre	7.16	8.45	7.64
Post 1	13.35	13.52	13.42
Post 2	9.89	10.35	11.62
Post 3	10.29	9.18	9.82
Pulse Rate			
Pre	68.9	77.9	72.3
Post 1	115.4	122.1	117.9
Post 2	79.5	93.2	84.7
Post 3	72.9	88.9	78.9
Pulmonary Depth			
Pre	625.4	703.3	692.2
Post 1	1719.4	2051.6	1844.2
Post 2	1400	1850	1680
Post 3	1300	1550	1540
Metabolic Rate			
Pre	11.53	11.25	11.43
Post 1	21.61	17.96	20.24
Post 2	12.45	12.39	12.43
Post 3	13.92	11.67	12.96

TABLE XI
(Continued)

WBC COUNT

Subject	1	2	3	4	5	6	Mean	% of Normal
Peklewsky								
Pre	--	--	4550	--	8500	--	6525	158%
Post	--	--	1110	--	9600	--	10350	
* Farmer								
Pre	--	--	7900	--	8950	--	8425	107%
Post	--	--	6500	--	11650	--	9075	
Buettner								
Pre	--	--	5100	--	6750	8400	6750	109%
Post	--	--	7400	--	--	7450	7375	
Smith								
Pre	--	--	5450	6050	7350	5850	6174	107%
Post	--	--	9500	4200	7650	6250	6640	
Mean Pre	--	--	6592	4556	7887	6585	6405	
Mean Post	--	--	9043	6125	9966	7175	8077	
% of Normal	--	--	106%	114%	126%	109%	126%	

TABLE XII
(Continued)

MEAN VALUES

Factors	P. E. Majors	Graduate Students	Group
Systolic Pressure			
Pre			127.5
Post 1			168.2
Post 2			128.6
Post 3			132.9
Diastolic Pressure			
Pre			66.4
Post 1			46.1
Post 2			60.2
Post 3			64.4

TABLE XIII

Values of Effects of Exercise

Graduate Students

Factor	Begin Study	End of Study	Signif. Level	Sign of Diff. with P. E. Begin	End
Recovery Index	21.5	19.2	0.5	0.5	0.3
Rest. Pulse Rate	84	70.6	0.3	0.4	0.4
Max. Pulse Rate	104	137	0.2	0.9	0.3
Rest. Sys. Press.	126.6	124	0.8	0.9	0.5
Rest. Dias. Press	69.3	85	0.3	0.6	0.2
Post. Sys. Press.	167.3	153.3	0.6	0.8	0.4
Post. Dias. Press.	51.3	39.3	0.3	0.7	0.7
Rest. Pulse Press.	57.3	42.3	0.2	0.6	0.5
Post Pulse Press.	116	119	0.8	0.4	0.4
Rest. Met. Rate	71.6	63.6	0.5	0.3	0.5
Post Met. Rate	98	90.06	0.5	0.5	0.7
Rest. Pulm. Vent.	8.3	8.1	0.6	0.6	0.2

TABLE XIII
(Continued)

Graduate Students

Factor	Begin Study	End of Study	Signif. Level	Sig. of Diff. with P.E. Begin	End
Post Pulm. Vent.	15.7	32.7	0.1	0.8	0.1
Rest. Resp. Rate	13.3	15.5	0.9	0.9	0.9
Post Resp. Rate	16.6	17.5	0.9	0.9	0.9
Rest. Resp. Depth	753	600	0.1	0.2	0.5
Post Resp. Depth	2126	1856	0.1	0.6	0.05
Pre Hemoglobin	14.1	15.2	0.8	0.6	0.7
Post Hemoglobin	12.7	15.5	0.6	0.9	0.6
Pre WBC Count	6850	8950	0.02	0.1	0.02
Post WBC Count	8083	11650	0.01	0.02	0.01
Pre Differential	Insufficient Data--				
Post Differential	Insufficient Date--				

TABLE XIV

Values of Effects of Exercise

P. E. Majors

Factor	Begin Study	End of Study	Signif. Level
Recovery Index	23.8	23.2	0.8
Rest Pulse Rate	70.4	68.8	0.8
Max. Pulse Rate	103.6	120.8	0.3
Rest. Sys. Press.	125.6	115.6	0.4
Rest. Dias. Press.	64.4	70.8	0.4
Post Sys. Press.	165.2	146	0.2
Post Dias. Press.	54	36.8	0.1
Rest Pulse Press.	61.2	46.8	0.2
Post Pulse Press.	105.2	109.2	0.7
Rest. Met. Rate	62.2	66.6	0.6
Post Met. Rate	91	124.7	0.1
Rest Pulm. Vent.	6.87	5.2	0.5

TABLE XIV

(Continued)

Values of Effects of Exercise

Factor	Begin Study	End of Study	Sig. Level
Post Pulm. Vent.	16.4	14.8	0.7
Rest Resp. Rate	14.2	14.4	0.9
Post Resp. Rate	18	18	0.9
Rest Resp. Depth	700	616	0.1
Post Resp. Depth	1880	1608	0.05
Pre Hemoglobin	13.9	13.9	0.9
Post Hemoglobin	12.8	13.2	0.9
Pre WBC Count	6720	6970	0.05
Post WBC Count	9380	7660	0.02
Pre Differential	Insufficient Data----------------		
Post Differential	Insufficient Data----------------		

TABLE XV

Coefficients of Correlation

Factors	P. E. Majors	Graduate Students	Group
Recovery Index-Maximum Pulse Rate	-0.1104	-0.6765	-0.9619
Recovery Index-Pulse Ratio	-0.7719	-0.2222	-0.5039
Pre- and Post-Pulse Rate	0.7595	0.6073	0.7268
Rest Pulse Rate-Increase	0.3005	-0.2446	0.1899
Pre-Pulse Rate-Sys. Press.	0.3929	-0.6090	0.3811
Pre-Sys. Press.-Pulse Press.	0.9136	0.9979	0.7919
Post-Sys. Press.-Pulse Press.	0.7565	1.----	0.9616
Post-Pulse Rate-Sys. Press.	-----	-----	0.7374
Post Pul. Vent.- Resp. Rate	----	-----	-0.3453
Pre-Pul. Vent-Resp. Depth	0.2126	2.---	0.4290
Post-Pul. Vent.-Resp. Depth	0.6330	0.6629	0.7838
Post Hem. Content-Hematocrit	----	----	-0.0624

TABLE XVI

PULSE-RATIO

	Mean
* Shapire	2.7
* Osborn	2.8
Buck.	2.5
Rummel	3.5
Pek.	2.8
* Farmer	2.7
Buettner	2.7
Smith	2.8